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A STUDY OF A WIND TUNNEL MEASUREMENT SYSTEM FOR UNSTEADY PRESSURES USING PNEUMATIC TRANSMISSION LINES

THESIS

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
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Master of Science

by

Mohammed Javed Khan
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Preface

This study is an application of the theory of cascaded pneumatic transmission lines in a low-cost pressure measurement technique. The primary purpose of this thesis was to study the feasibility of a tube-scanning valve system as a technique for the measurement of unsteady pressures in the Air Force Institute of Technology (AFIT) 5-foot wind tunnel.

To achieve this goal, a tube-scanning valve system based on a commercially available pressure scanning valve was configured and installed in the wind tunnel. A computer program was used to theoretically predict the system gains. The gains were compared with experimental results to determine the effects of tunnel speeds, flow perturbations, and structural vibrations.

My sincerest appreciation and gratitude are extended to all of the extremely competent personnel of the AFIT workshops and to Messrs. N. Yardich and W. S. Whitt, of the AFIT 5-foot wind tunnel, who were always ready to extend their help whenever needed. I would especially like to thank Dr. M. E. Franke, my thesis advisor, who first introduced me to the theory of pneumatic transmission lines and whose suggestions and assistance were extremely valuable. I would also like to thank Dr. H. C. Larsen, whose ideas were very helpful in the wind tunnel testing phase.

Finally, I would like to mention the patience and understanding of my wife which made this work possible.

Mohammed Javed Khan

Table of Contents

List of Figures

List of Tables

List of Symbols

Symbol	Definition
cps	cycles per second
db	decibels
f	frequency
Hg	inches of mercury
H_t	transducer cavity depth
Hz	hertz
ID	internal diameter
in	inches
L	flexible tube length
mph	miles per hour
mV	millivolts
P_m	mean line pressure
P_r	receiving end pressure
P_s	sending end pressure
P_7	receiving end pressure at port no. 7
rms	root means square

Abstract

The application of pneumatic transmission lines theory to a tube-scanning valve system for unsteady pressure measurements in the AFIT 5-foot wind tunnel is investigated. Transfer gains of various tube-scanning valve configurations were experimentally measured and the validity of a theoretical model verified for a frequency range of 20 Hz to 140 Hz.

The selected system having a 0.0625-in. ID flexible tube of 84 in. length connected to a scanning valve was installed in the wind tunnel. Unsteady pressures introduced over an 18 percent airfoil at zero angle of attack were measured with this system. Data were collected for 0, 40, 60, 80, 100, and 150 mph for a frequency range of 30 Hz to 55 Hz. Comparison of theoretical and experimental results for one data point revealed the dependence of the verification of the system measurement accuracy on the wind tunnel speeds and flow perturbation characteristics. Theoretical predictions were verified for 30, 35, and 40 Hz only.

I. Introduction

Background

The high performance-low weight configurations of today's typical aircraft have forced the designers to assign a much higher priority to the effects of unsteady aerodynamics than in the past. The procedure normally used to gather data for the study of these effects has been through theoretical models whose results are augmented by wind tunnel tests. The complicated nature of theoretical models used in the transonic regimes necessitates the requirement of experimental verifications even more. The various methods employed in the wind tunnel testing are scaled aerodynamics and flutter models (Refs 1, 2) to obtain airloads, vibration modes, and frequency data for the determination of structural strength, flutter, control reversal speeds, etc. This study is directed towards the techniques of measuring the unsteady pressures over the model to predict the aerodynamic load distributions.

The predominant method for wind tunnel unsteady pressure data collection has been through the use of implanted pressure-sensitive devices in the model which relay the pressure signals as electrical impulses. This method, although very reliable, has obvious disadvantages for use in testing complex configurations. The increase in the number of points of interest on the model results in a proportionate increase in the number of pressure transducers required. This, coupled with the extremely sensitive nature of the transducers to vibrations and mishandling during installation and removal, not only introduces extraneous noise but also increases the testing costs. These problems can be overcome by other measurement techniques, which can not only be accurate but also cost effective.

In recent years, advances in the accurate predictions of the dynamic response of pneumatic transmission lines (Refs 3, 4, 5) has made it possible for these analyses to be easily applicable in practical situations. This was an ideal source for the wind tunnel engineer, who is quite at home with tube-manometer pressure measurement systems. The use of tubes to transmit unsteady pressures from the wind tunnel model to a transducer located outside the tunnel was studied by Destuynder and Tijdeman (Ref 6). Their results indicated the possibility of a measurement system using tubes to transmit the pressure signals to a transducer scanning these tubes periodically. Such a system would thereby reduce the number of transducers required, even for a complex configuration.

Objective

The objective of this thesis study was to design and fabricate a wind tunnel measurement system for measuring unsteady pressures with a tube system and a pressure scanning valve. The scope of the study was limited to testing a prototype system in the Air Force Institute of Technology (AFIT) 5-foot subsonic wind tunnel, located at Wright-Patterson Air Force Base, Ohio. To achieve this, the work was divided into the following main areas:

a. System Configuration Synthesis. This consisted of the theoretical determination and the experimental verification of the response of various tube-scanning valve configurations to a sinusoidal pressure signal. The effects of transducer cavity volumes, tube lengths, and mean line pressures were studied.

b. Application Study. The measurement of unsteady pressure distribution over a two-dimensional airfoil installed in the AFIT 5-foot wind tunnel. This required the fabrication of a wind tunnel model, flow perturbation mechanism to introduce oscillatory signals, and the signal transmission and processing apparatus.

II. System Configuration Synthesis

Introduction

In this chapter, the procedure to determine the system configuration compatible with its future application is outlined. This effort also resulted in the experimental verification of the mathematical model predictions of the response of the system. The system design was based on a commercially available Scani-Valve Corp Model J9 scanning valve (Figure 1). The minimum tube length was constrained to be 84 in. considering the system application in the AFIT 5-foot wind tunnel. The studies were based on a tube ID of 0.0625 in., a commonly used size in wind tunnel testing. The frequency range of the testing was restricted to 20 Hz to 140 Hz with 20 Hz increments, due to the limitations on the vibration source to be used in the wind tunnel application (Chap III). The measurements of the system response were made for different configurations to a sinusoidal pneumatic signal and the effects of various system variables were studied. These data were compared to the predictions of a theoretical model. Based on the results of the above procedure, a system was selected for use in the wind tunnel pressure measurement phase of the study (Chap III).

Theoretical Model

The theoretical model used was based essentially on the approach by Nichols (Ref 5), with improvements implemented for the low frequency approximations to the Bessel Functions involved in the analysis put forward by Krishnayer and Lechner (Ref 7). An existing computer program incorporating this model was utilized to predict the theoretical response

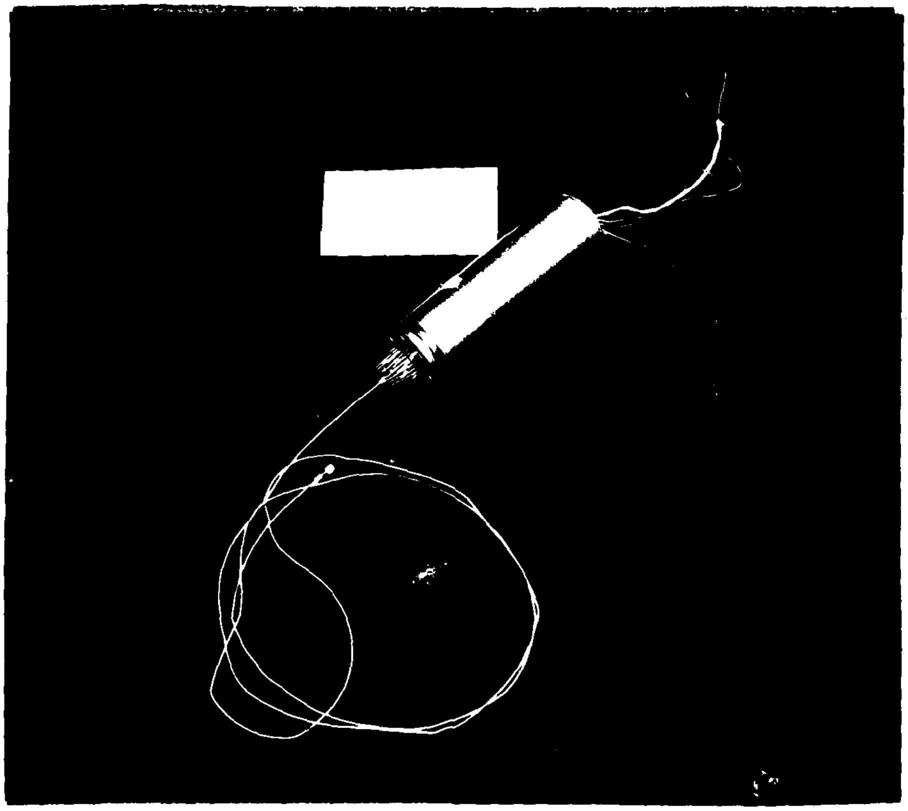


Figure 1. Scanning Valve

of the system. This computer program was developed by Malanowski (Ref 8) originally for the study of dynamic response of a fluidic network, with the capabilities of handling branch lines with discontinuities in diameters (cascaded lines) with or without mean flow. This program was adapted to a system without branch lines for the purposes of this study. The accuracy of this adaptation was later verified by the comparison of the theoretical predictions to the experimental data.

Experimental Setup

The apparatus used for the experimental determination of the system response (Figure 2) consisted of a pneumatic signal source fed by an electrical signal from a wave analyzer. The sinusoidal pneumatic signal generated was fed into a scanning valve via a flexible plastic tubing (0.0625-in. ID). A piezoelectric pressure transducer was located at the sending end of the system to detect the amplitudes of the input signal. The scanning valve had 48 input ports and a pressure transducer (receiving end). An electric motor could periodically connect the pressure transducer to each input port through ducting of variable diameters (Figure 3). The signals thus detected by the sending and receiving end transducers were amplified by charge amplifiers and displayed on an oscilloscope for visual reference. The signal rms amplitudes were read from a wave analyzer.

Experimental Procedure

The dynamic response of various configurations was determined experimentally for the frequency range of 20 Hz to 140 Hz. The scanning valve transducer remained connected to the plastic tubing throughout the tests. The effects of scanning valve transducer cavity depths, tubing lengths, and line mean pressure were studied. The first tests consisted of

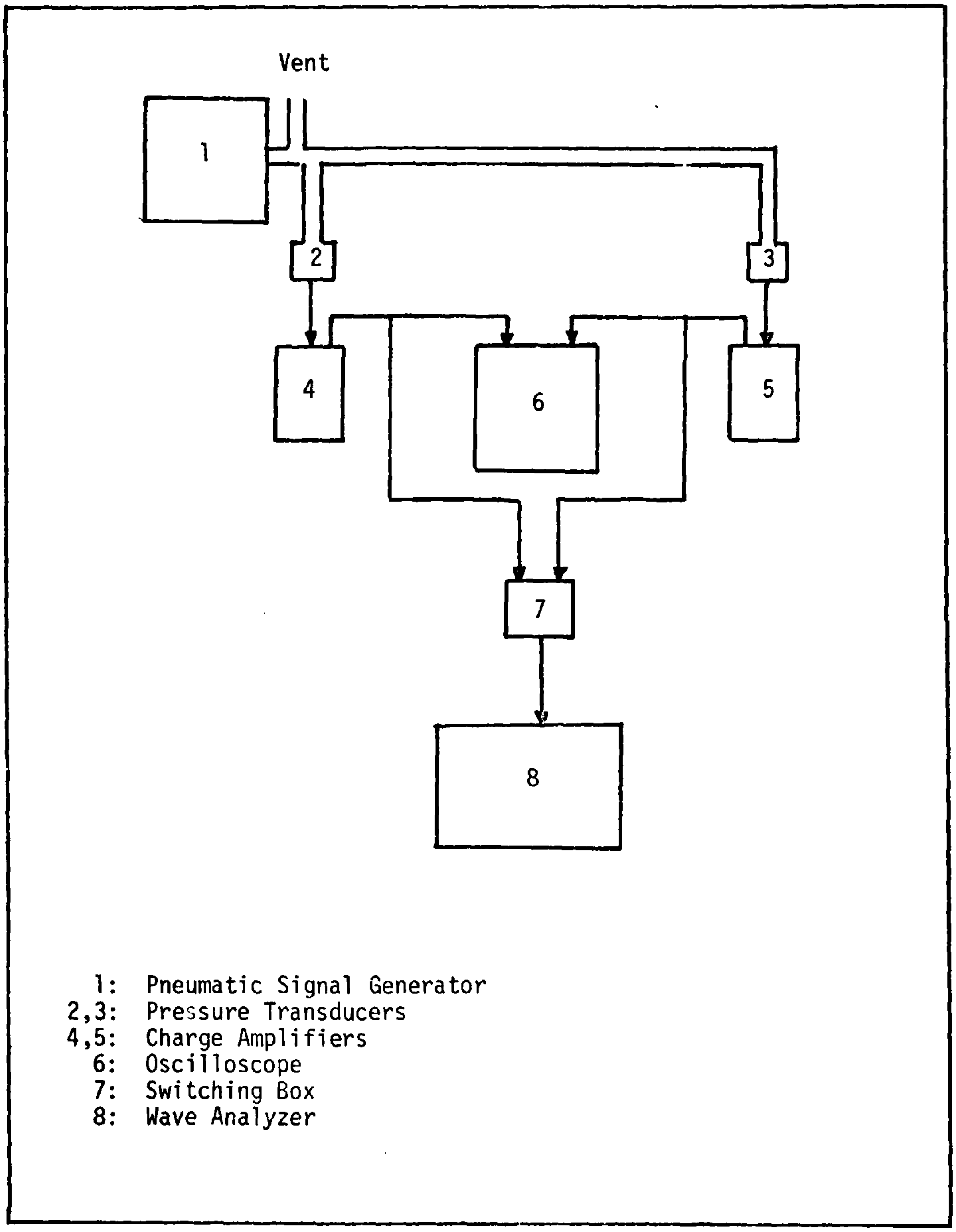
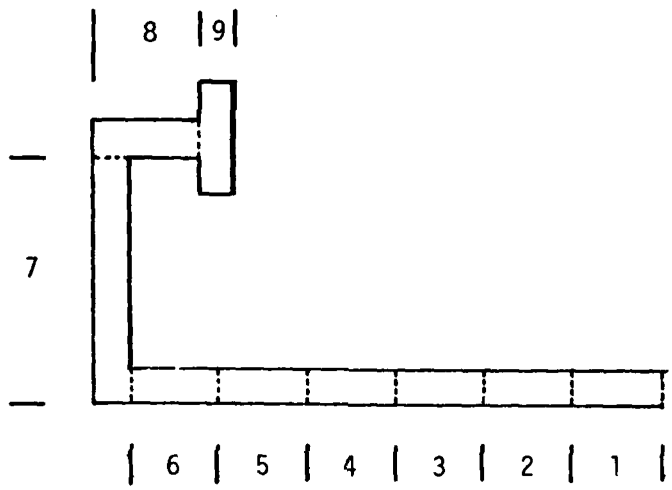


Figure 2. Schematic of Apparatus Setup for System Synthesis Study



Line Segment	Length Inches	Diameter Inches
1	1.210	0.040
2	0.069	0.059
3	0.145	0.040
4	0.081	0.033
5	0.045	0.029
6	0.065	0.020
7	0.480	0.031
8	0.180	0.031
9	0.020	0.375

Figure 3. Schematic of Scanning Valve Internal Ducting

studying the effects of the transducer cavity depths. These depths were adjusted by using 0.01-in. thick spacer shims. Tests were conducted for depths of 0.04, 0.03, 0.02, and 0.01 in. The sending and receiving end amplitudes were recorded for the frequency range for each transducer cavity (Table I). The plastic tubing length and mean line pressures were maintained at 84 in. and 10 Hg, respectively, for these tests. The next series of tests consisted of using plastic tubing of various lengths connecting the scanning valve to the pneumatic signal source. The sending and receiving end signal amplitude data for each tube length were recorded (Table II). The transducer cavity depth and mean line pressures were kept fixed at 0.02 in. and 10 Hg during the measurements. The final tests consisted of studying the effects of mean line pressures on the system response at a constant transducer cavity depth (0.02 in.) and tube length (84 in.). The sending and receiving end amplitudes were measured for mean line pressures of 5, 10, and 15 Hg (Table III). During all of these tests, no effort was made to keep the input signal amplitude at a constant level.

Observations and Conclusions

It was observed that smaller transducer cavities resulted in system gains (P_r/P_s) closer to the theoretical predictions in the frequency range of 20 Hz to 140 Hz (Figure 4). However, reduction of the cavity depth beyond 0.02 in. did not allow the transducer diaphram to respond properly to the pressure variations. The increase in the lengths of the plastic tubing increased the signal attenuations in the range of interest (Figure 5). It was also observed that the mean line pressure did effect the system response (Figure 6), thereby emphasizing the

TABLE I

Effect of Transducer Cavity on System Gain

f	Gain (db)		
	H_t 0.04 in.	H_t 0.03 in.	H_t 0.02 in.
21	-1.26	1.00	1.25
40	-3.90	0.47	0.67
60	-7.69	-2.57	-2.57
81	-9.10	-1.98	-1.71
99	-8.67	-0.98	-0.62
120	-12.33	-3.52	-2.83
140	-14.65	-4.49	-3.69

$L = 84$ in., $P_m = 10$ Hg

TABLE II

Effect of Line Length on System Gain

f	Gain (db)		
	L=84 in.	L=96 in.	L=108 in.
20	2.98	3.23	2.86
40	1.79	-0.25	-1.72
60	-1.72	-2.50	-2.50
81	-1.11	-0.63	-1.83
99	0.50	-2.16	-4.15
120	-2.05	-3.74	-3.88
140	-3.34	-1.94	-4.01
H_t = 0.02 in., P_m = 10 Hg			

TABLE III

Effect of Mean Line Pressure on System Gain

f	Gain (db)		
	P 5^{m}Hg	P 10^{m}Hg	P 15^{m}Hg
21	1.34	1.25	1.38
40	1.94	0.67	1.05
60	-2.61	-2.52	-2.18
81	-2.18	-1.71	-1.34
99	-1.02	-0.62	0.23
120	-3.74	-2.83	-2.50
140	-4.08	-3.69	-3.52

H_t = 0.02 in., L = 84 in.

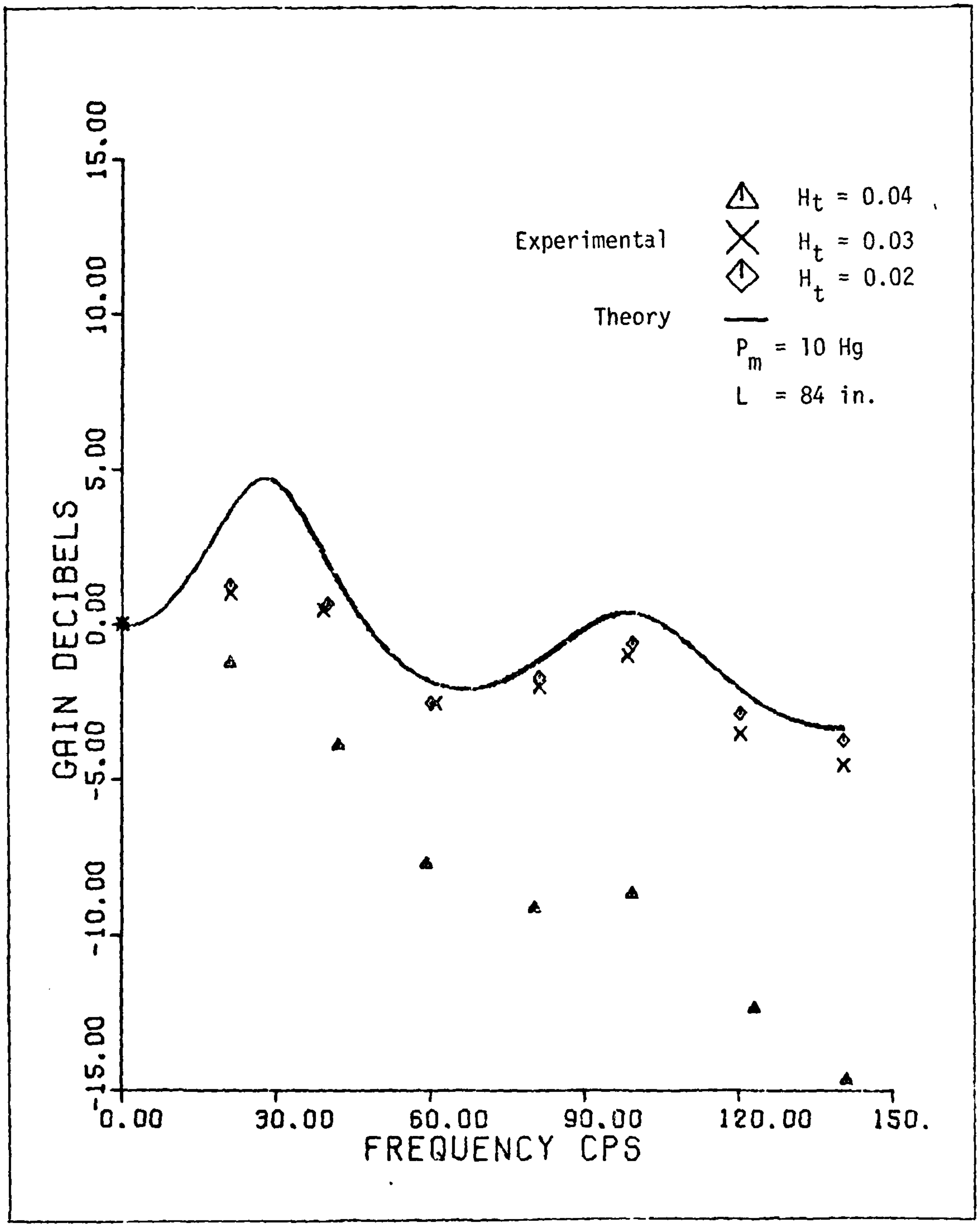


Figure 4. Effect of Transducer Cavities on System Gain

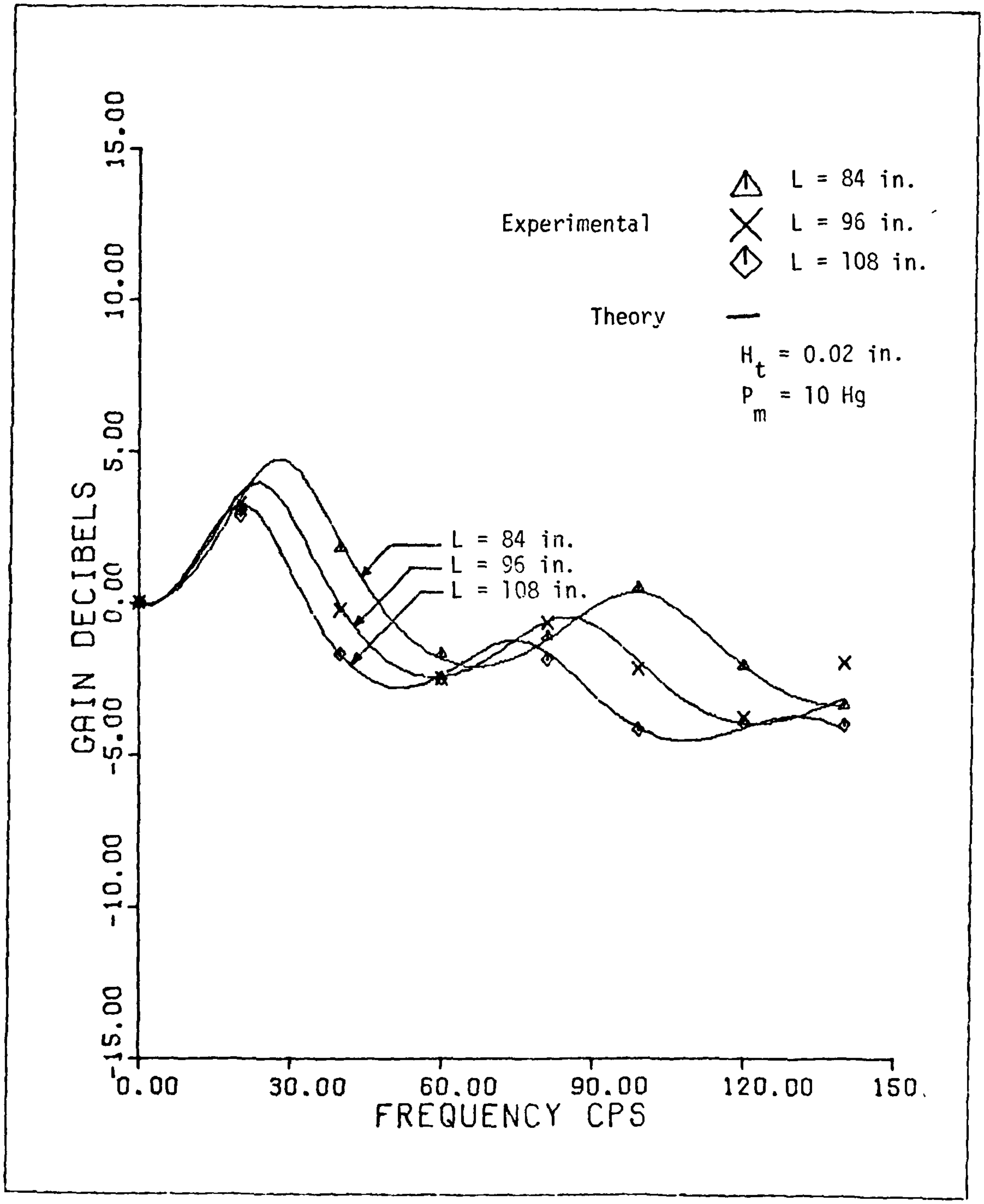


Figure 5. Effect of Line Length on System Gain

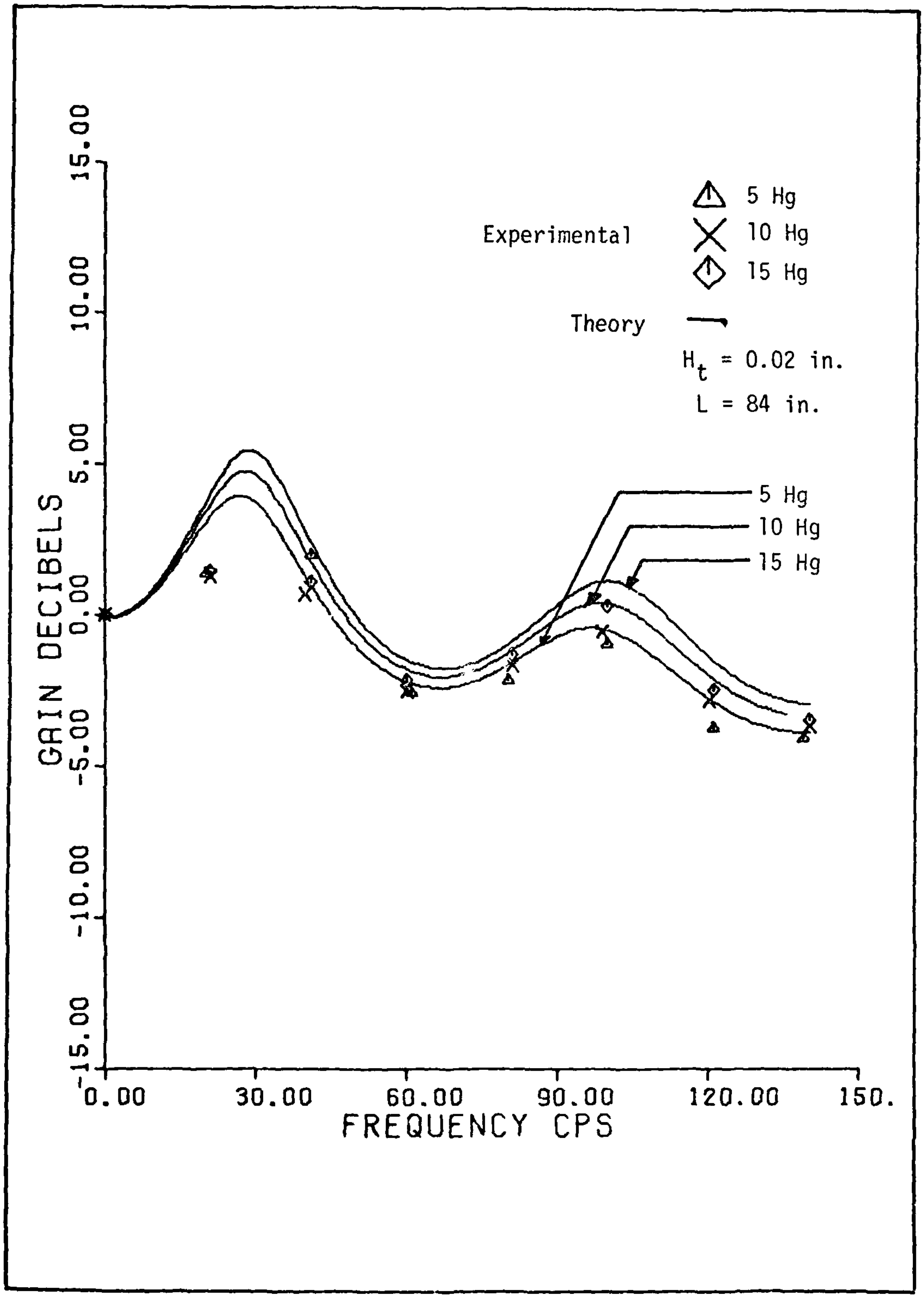


Figure 6. Effect of Mean Line Pressure on System Gain

requirement for measurement of the static pressures if the system is used for wind tunnel pressure measurements. The experimental data was then compared with the theoretical predictions and was observed that the theoretical model predicted the system response very closely (Figures 4, 5, 6). It was also established that the flexibility of the plastic tubing and the adaptation of the computer program did not introduce inaccuracies in the predictions. The final system configuration thus selected had a plastic tubing of 0.0625-in. ID and 84 in. in length connected to the scanning valve, having a transducer cavity depth of 0.02 in.

III. System Application Study

Introduction

The system configured as a result of the study of Chapter II was used in the AFIT 5-foot subsonic wind tunnel to measure unsteady pressures over a two-dimensional airfoil with a moveable trailing edge flap to demonstrate the feasibility of the system as a practical measurement technique. Two methods of airflow perturbation were employed in order to introduce sinusoidally oscillating airflow over the model. The first method used the moveable trailing edge flap, and the second utilized a flat plate vibrating in the vicinity of the model. The unsteady pressures thus introduced were measured by the tube-scanning valve system, and the results of at least one data point were compared with measurements made on the airfoil itself using an implanted pressure transducer. The continuous scanning option of the scanning valve was not utilized due to its high scanning rate. Data were collected for tunnel speeds of 40, 60, 80, 100, and 150 mph for a frequency range of 30 Hz to 55 Hz. The pressure distribution over one side of the airfoil was measured for 30 Hz at 80 mph.

Experimental Apparatus

The experimental setup consisted primarily of a wind tunnel model, flow perturbation mechanism, and the instrumentation.

a. Wind Tunnel Model (Figure 7). An 18 percent quarter-chord thick airfoil with a 25 percent thick moveable training edge flap was used. The model was enclosed in circular end plates to simulate two-dimensional flow. Twenty-two pairs of surface pressure taps, symmetrically located about the model center line, were used to transmit the

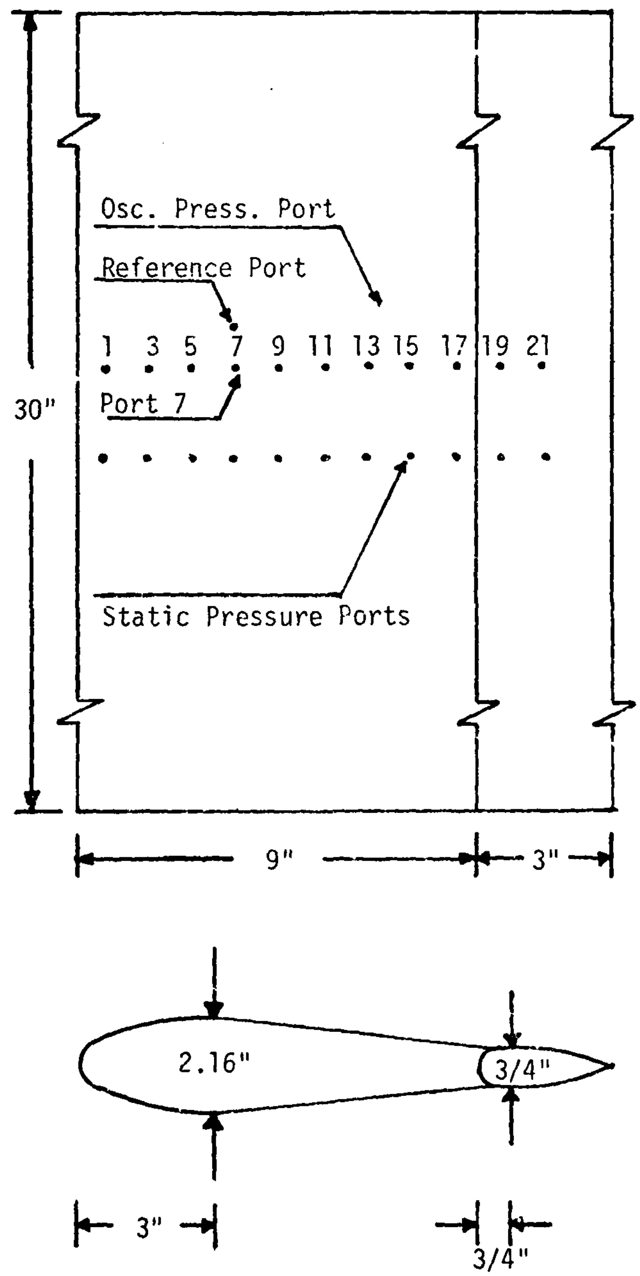


Figure 7. Schematic of Wind Tunnel Model

chordwise local oscillatory and static pressure to the scanning valve and manometers through 0.0625-in. plastic tubing. A reference port was also located on the model (Figure 7). A transducer imbedded in the model measured the local oscillatory pressure (Figure 8) to verify the predictions based on the tube-scanning valve measurement for the reference port.

b. Flow Perturbation Mechanism. Two techniques were used to introduce sinusoidal oscillating pressure perturbations in the airflow. The first method used the moveable trailing edge flap of the model (Ref 9) which was oscillated by an electromagnetic shaker using a simple lever mechanism (Figure 9). The second technique made use of the large amplitudes of various flat plates vibrated close to their natural frequencies in the vicinity of the model by the shaker (Figure 10). Plates of varying dimensions (Figure 11) were used to introduce various frequency signals in the airflow. The amplitude of vibration of these plates could be varied to oscillate the flow at controlled amplitudes.

c. Instrumentation (Figure 12). The static pressures over the model were measured using alcohol manometers. The outputs of the implanted and scanning valve transducers were amplified by electrostatic charge amplifiers and fed to a Rockland FFT512/S real time spectrum analyzer. This spectrum analyzer had varying sample numbers and bandwidth capabilities. A bandwidth of 500 Hz and a sample number of 16 was used to determine the average rms amplitudes. The analyzer also had the facility of dual display memory and signal comparison.

Testing Procedure

The model was installed at zero angle of attack. The measurement system was first checked for noise and turbulence at speeds of 0, 40, 60,

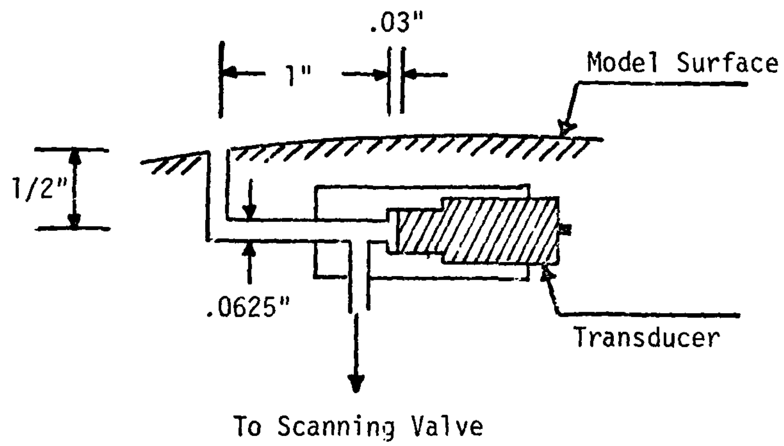


Figure 8. Schematic of Reference Port Transducer Installation

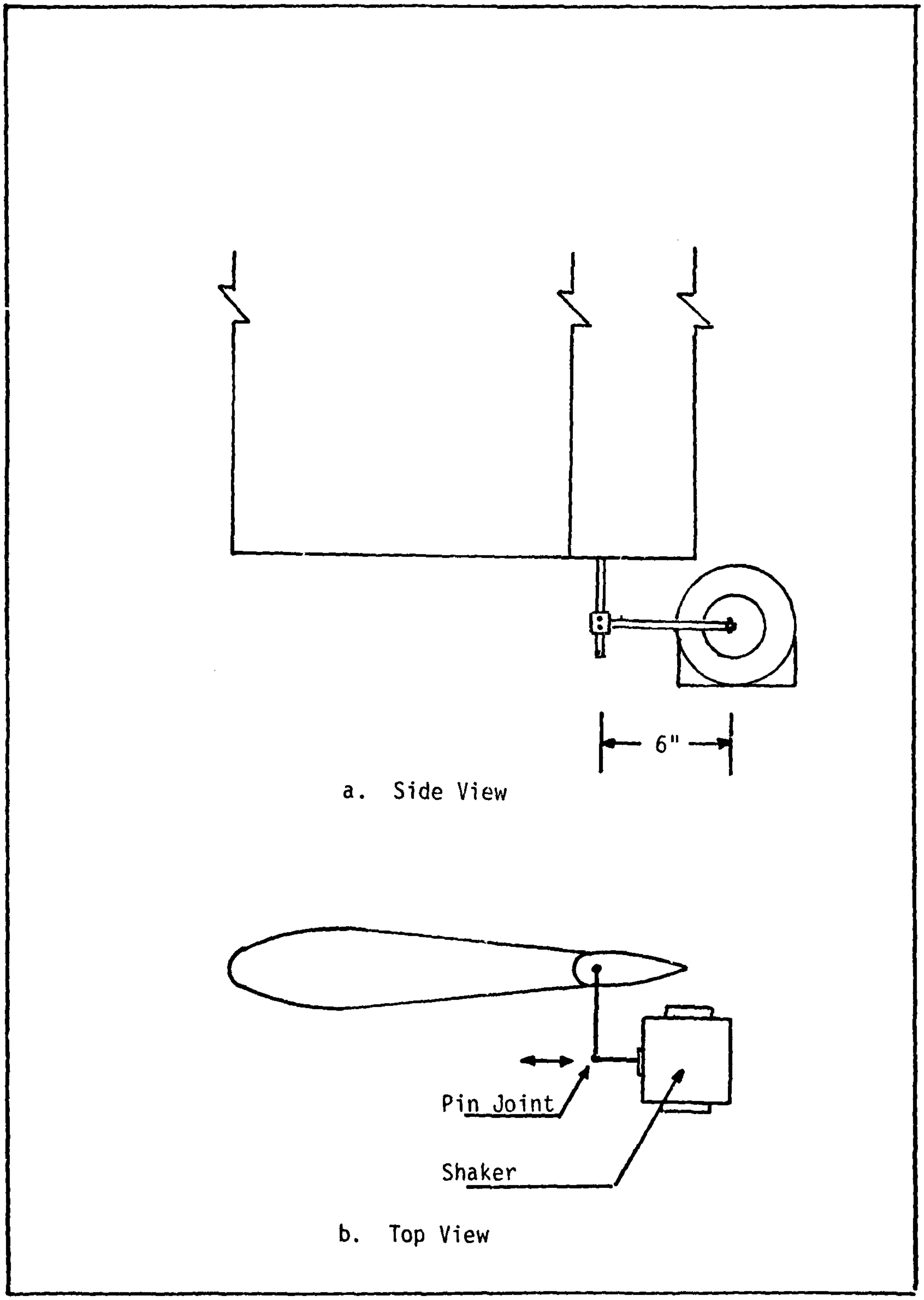


Figure 9. Trailing Edge Flap Vibrating Mechanism

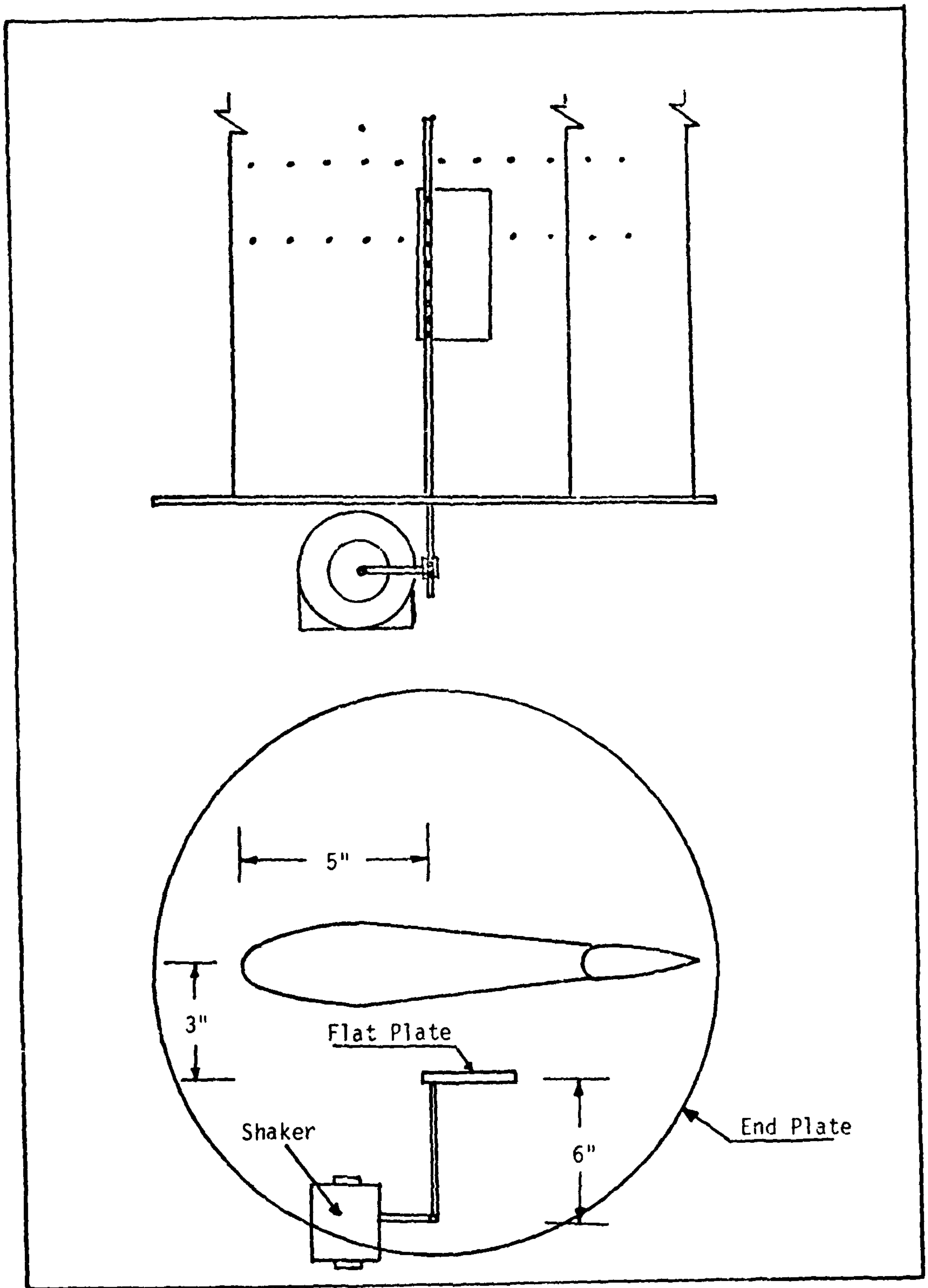


Figure 10. Plate Vibrating Mechanism

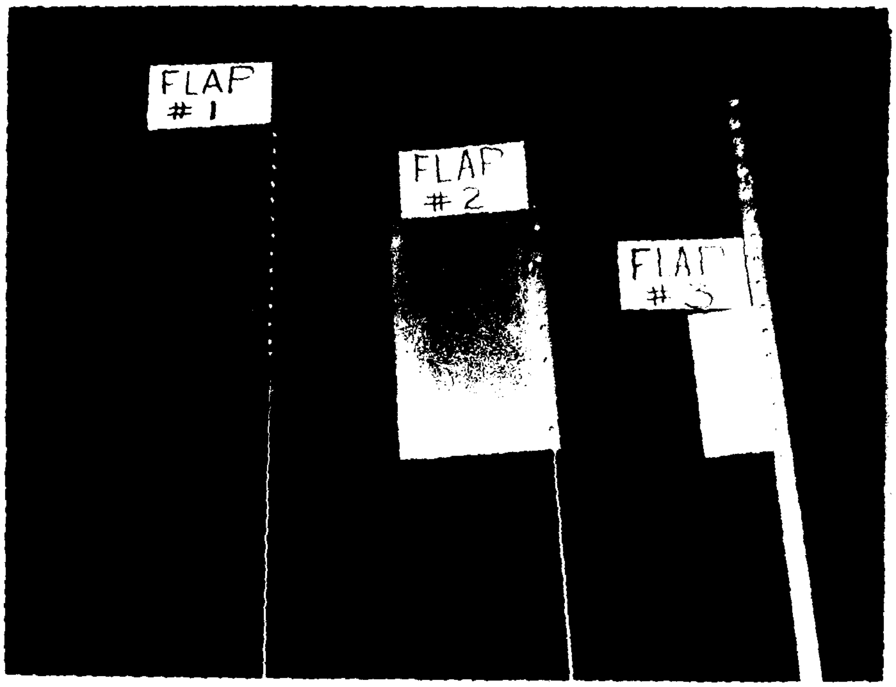


Figure 11. Plates Used to Introduce Flow Perturbations

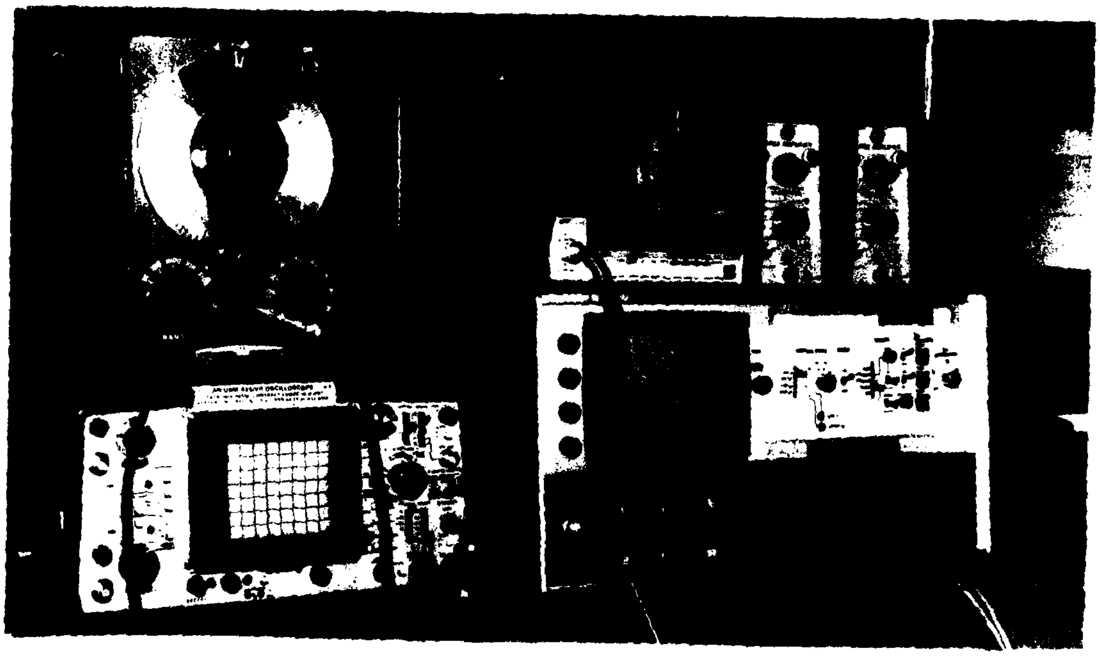


Figure 12. Wind Tunnel Instrumentation

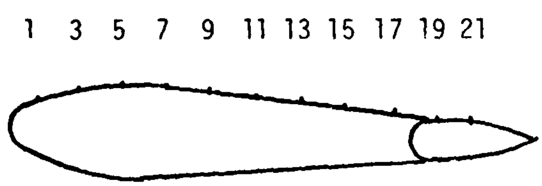
80, 100, and 150 mph for the frequency range of 30 Hz to 120 Hz. The trailing edge flap remained fixed at zero angle during these attacks.

Perturbations were then introduced in the airflow by vibrating the trailing edge flap. This method was, however, abandoned after establishing that no measurable signal was reaching the reference port. The second technique of inducing oscillatory pressure disturbances was then employed. This technique resulted in perturbations on one side of the model only. The trailing edge flap was fixed at zero angle, and the gap between it and the airfoil was sealed during this procedure. The flat plate was installed at various locations in the vicinity of the model to determine a position which would introduce a measurable signal at the reference port. After determining this position (Figure 10), the tunnel was then run at various test speeds and the plates vibrated at various amplitudes. Data could be collected at the reference port and port number 7 for 30, 35, 40, 45, 50, and 55 Hz only. The pressure distribution over the side exposed to the perturbations was measured for a frequency of 30 Hz at a tunnel speed of 80 mph (Table IV). Figure 13 shows a typical unsteady pressure distribution along the chord length. The high scan rate of the scanning valve did not allow the spectrum analyzer to take the required number of signal samples for each port. This necessitated the manual connection of each pressure port to the scanning valve during measurement of the pressure distribution along the chord length.

TABLE IV

Unsteady Pressure Distribution Over One Side of the Wind Tunnel Model at 80 mph and 30 Hz

Port Number	P_r(mV)	P_s(mV)
1	0.756	0.569
3	1.360	1.023
5	2.040	1.534
7	3.010	2.264
9	3.700	2.783
11	3.280	2.467
13	2.770	2.083
15	2.420	1.820
17	2.010	1.512
19	1.300	0.978
21	0.725	0.545



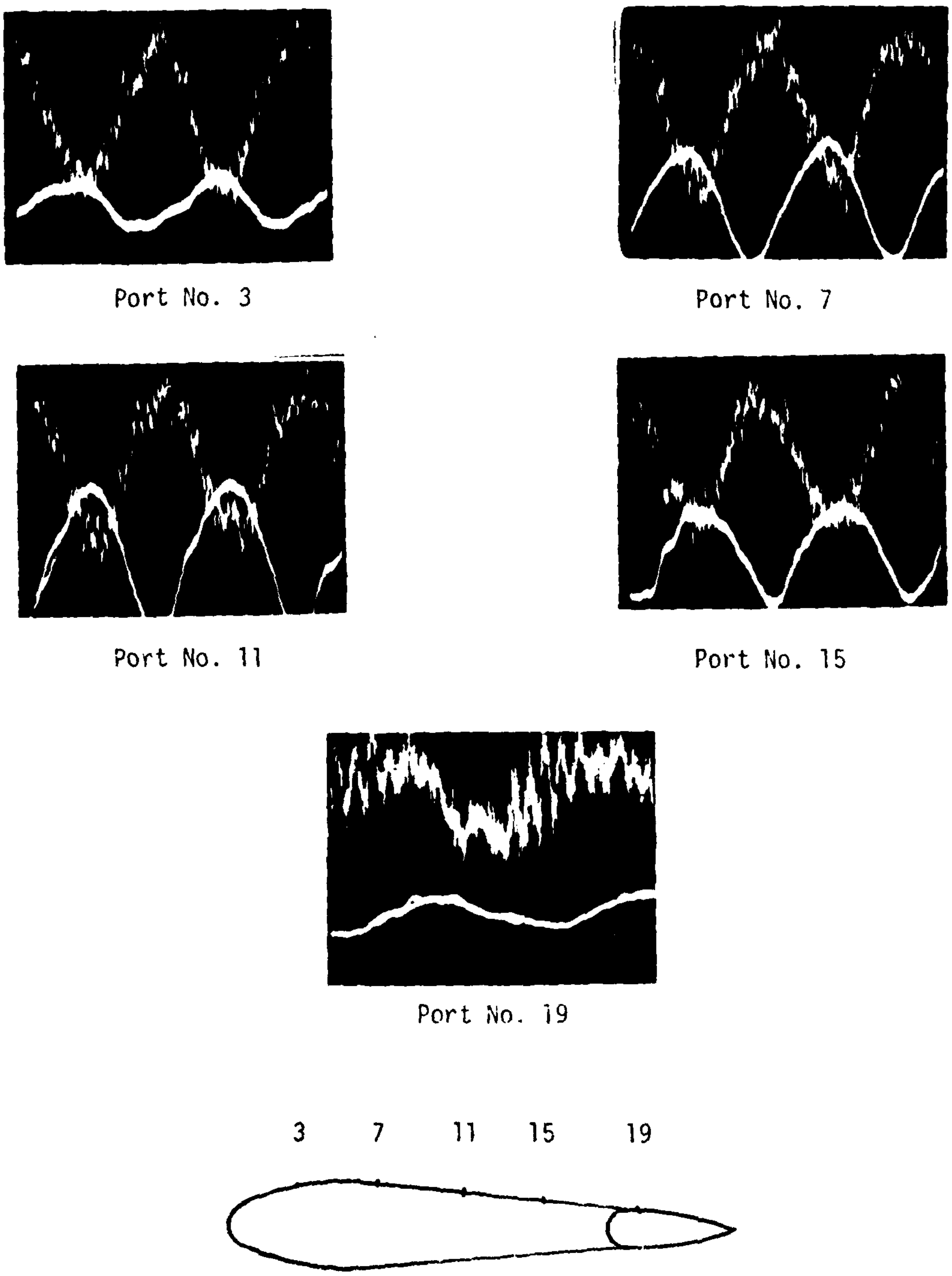


Figure 13. Typical Unsteady Pressure Distribution over the Wind Tunnel Model at 35 Hz and 80 mph (Upper Trace: Perturbation at Reference Port; Lower Trace: Local Perturbation)

IV. Discussion of Results

It was noted during the wind tunnel tests that the techniques for introducing pressure perturbations limited the verification of this measurement system. It was also observed that the pressure perturbations resulting from these techniques had amplitudes having time as well as spatial dependency. The accuracy of the measurements made by this system was found to be affected only by the pressure perturbation characteristics. The flow turbulence did not cause any errors in the measurements as it was low compared to signal amplitudes and was randomly distributed over the spectrum (Table V). The changes in wind tunnel speeds during these tests had a negligible effect on the theoretical predictions. This was because the static pressure changes along the model chord were very small due to the low testing speeds.

Effects of Pressure Perturbation Introducing Techniques

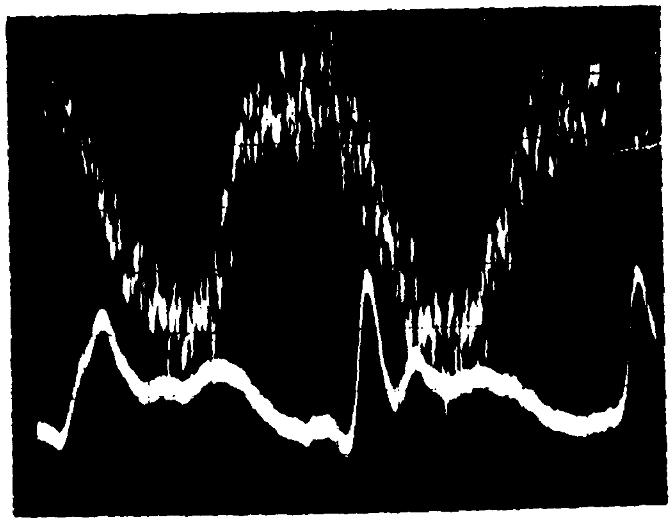
The oscillating trailing edge flap did not produce signals of sufficient amplitudes which could be measured at the reference port. The independent flat plate perturbation introducing technique was more successful in producing a detectable pressure signal at the reference port. This technique also allowed the sealing of the flap-airfoil gap. This gap was found to be affecting the sinusoidal characteristic of the pressure perturbations (Figure 14). This perturbation introducing technique, however, had certain undesirable characteristics influencing this study.

a. An increase in the plate vibrations beyond certain amplitudes, to increase the perturbation amplitudes, resulted in structural vibrations

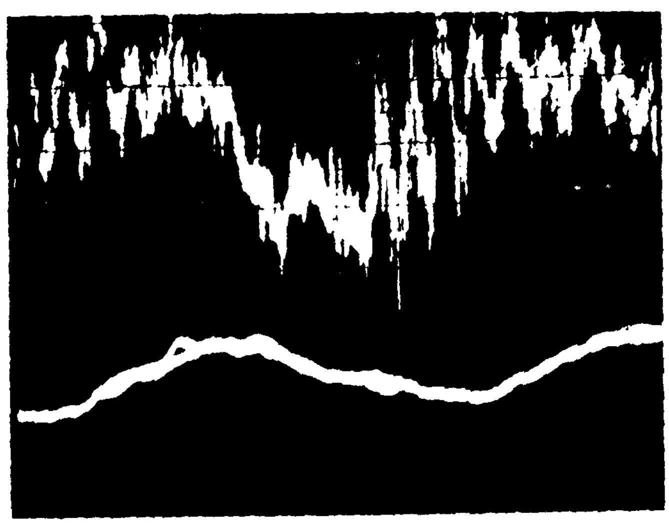
TABLE V

Typical Wind Tunnel Turbulence Level
at the Reference Port at 80 mph

f	P_s(mV)	P_r(mV)
10	0.112	0.0055
20	0.200	0.087
30	0.092	0.057
35	0.098	0.062
40	0.098	0.059
45	0.081	0.051
50	0.094	0.051
55	0.089	0.039
60	0.609	0.198
65	0.110	0.049
70	0.120	0.069
75	0.0781	0.059
80	0.124	0.062
85	0.076	0.054
90	0.071	0.046
100	0.074	0.063



a. With Air Leackage (Upper Trace: Signal at Reference Port; Lower Trace: Signal at the Trailing Edge Flap)



b. Without Air Leakage (Upper Trace: Signal at Reference Port; Lower Trace: Signal at the Trailing Edge Flap)

Figure 14. Effect of Air Leakage Between Trailing Edge Flap and Airfoil

of the wind tunnel model. These vibrations were picked up by the implanted transducer, resulting in erroneous detection of the pressure perturbation amplitudes. It was observed that in such cases an increase in pressure perturbation amplitudes, although being registered at the scanning valve, were being measured erratically by the implanted transducer. These measurements, therefore, could not be used for comparison purposes. Figure 15 shows a typical spectrum analyzer display of such structural vibrations for a pressure perturbation frequency of 30 Hz and wind tunnel speed of 80 mph at the reference port. It could be seen from this figure that the signal being detected at the scanning valve (lower trace) is composed mainly of a single frequency which was the pressure perturbation frequency. The signal detected by the implanted transducer (upper trace) has not only the pressure perturbation but also the structural vibrations.

b. The plates used for introducing flow perturbations vibrated with unequal amplitudes along their lengths. These amplitudes also varied with time, even for a constant shaker amplitude. This resulted in pressure perturbations amplitudes which were not only time dependent but also varied with the measurement location. The comparison of measurements made at port number 7 and the reference port (Table VI) confirmed this observation.

c. The theoretical predictions were not supported by experimental measurements for the lower values of testing speeds. This was primarily due to the structural vibrations picked up by the implanted transducer. These vibrations again were the result of the large plate amplitudes which were needed for introducing a detectable pressure perturbation at low speeds. The prediction accuracy, however, improved with increase in testing speeds (Table VII). Increase in the wind tunnel speeds, however, resulted in larger pressure perturbations for lesser plate amplitudes,

Figure 15. Typical Structural Vibration Effects (Upper Trace: Signal Detected by the Implanted Transducer; Lower Trace: Signal Detected by the Scanning Valve Transducer)

TABLE VI

Effect of Spanwise Location of Pressure Ports on Detected Perturbation Amplitudes

f	P_r(mV)	
	Port 7	Ref Port
30	2.95 4.01 5.43 6.28	2.68 3.58 4.75 4.59
35	8.87 5.06	4.9 3.04
40	1.29 2.6 5.34 3.11	1.26 2.42 4.47 3.39

thereby reducing the structural vibrations. The plates could not be vibrated at controllable frequencies and amplitudes at wind tunnel speeds higher than 80 mph due to the turbulence induced flutter of these plates. This resulted in undesirable structural vibrations and nonsinusoidal pressure perturbations.

TABLE VII

Effect of Wind Tunnel Speed on Measurement Accuracy

f	Gain (db)			
	40 mph Experimental	60 mph Experimental	80 mph Experimental	Theory
30	-4.0 -5.5	1.9 1.22	2.8 2.8	2.475
35	-14.3 -14.9	-5.5 -6.5	1.9 1.4	1.457
40	-8.1	-1.0	0.2	0.257

Effects of Pressure Perturbation Characteristics

The accuracy of the pressure measurements made for cases when the pressures were clean sinusoidal perturbations was validated by the implanted transducer measurements (Table VIII). Figure 16 shows a typical spectrum analyzer display for a clean sinusoidal signal at 30 Hz and 80 mph at the reference port. The upper trace is the signal detected by the implanted transducer, and the lower trace is the signal reaching the scanning valve. The smaller amplitude peak in both the traces is the 60 Hz power line hum. At frequencies other than a specific one for each plate, the pressure perturbations introduced by it were not composed of a single frequency. Figure 17 shows a spectrum analyzer display of such a signal at the reference port. The upper trace is the signal detected by the implanted

TABLE VIII

Comparison of Experimental and Theoretical Results for the Reference Port at 80 mph

f	P_s(mV)	P_r(mV)	Gain (db)		Remarks
			Exper.	Theory	
30	1.83	2.68	3.3	2.475	Flap #1
	2.58	3.54	2.8		
	3.43	4.75	2.8		
	3.90	5.49	2.8		
35	3.9	4.9	1.9	1.457	Flap #2
	2.58	3.04	1.4		
40	1.19	1.26	0.4	0.257	Flap #3
	2.21	2.42	0.7		
	3.04	3.11	0.2		
	4.34	4.47	0.2		

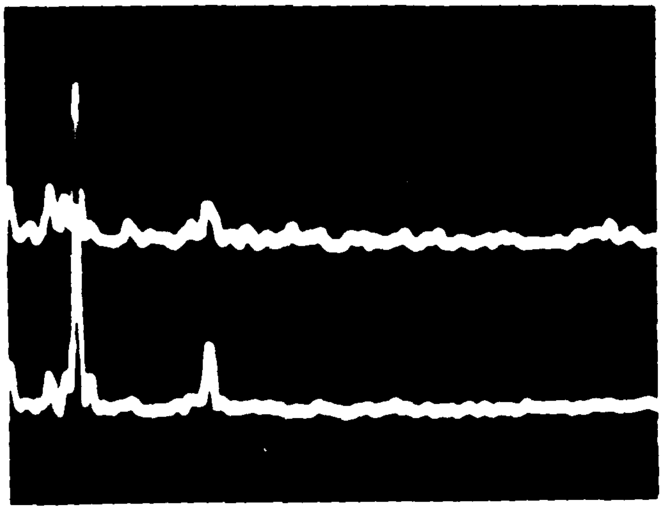


Figure 16. Typical Sinusoidal Flow Perturbation (Upper Trace: Signal Detected by the Implanted Transducer; Lower Trace: Signal Detected by the Scanning Valve Transducer)

transducer, and the lower trace shows the detected signal reaching the scanning valve. This signal is composed of two distinct frequencies of 28.5 Hz and 35 Hz. It can be seen that both the frequencies are being detected at the scanning valve as well. This indicates that both the frequencies were present in the perturbation signal. The theoretical predictions for such cases were also not supported by the experimental measurements.

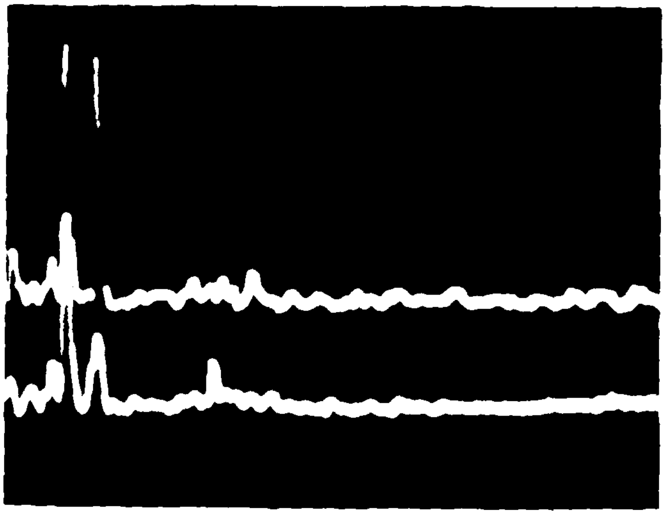


Figure 17. Typical Nonsinusoidal Flow Perturbation (Upper Trace: Signal Detected by the Implanted Transducer; Lower Trace: Signal Detected by the Scanning Valve Transducer)

V. Conclusions

The feasibility study for the tube-scanning valve measurement system was accomplished by using it in the AFIT 5-foot subsonic wind tunnel. The credibility of the system could be established only for certain test conditions. The measurement accuracy was verified for 30, 35, and 40 Hz at 80 mph for sinusoidal pressure perturbations. The test conditions also affected the instrumentation requirements for using this system as a practicable measurement technique.

This study led to the following conclusions about the measurement technique:

a. This technique is fairly insensitive to the structural vibrations of the model.

b. The pressures are accurately predicted for a sinusoidal pressure perturbation.

c. No comment can be made about the measurement accuracy of the system when subjected to a nonsinusoidal pressure perturbation. The discrepancy between the theoretical predictions and experimental measurements (at the model surface) may well have been due to the transducer's characteristics as exhibited by the implanted transducer during structural vibrations (Ref page 27). This point, however, needs further investigation.

d. For wind tunnel speeds of 80 mph and below, static pressure measurements are not needed for each chordwise position and test speeds.

The study also pointed out certain other aspects which were primarily due to the technique used for introducing pressure perturbations. These aspects, which not only can affect the efficiency of the system but also introduce errors, were:

a. The continuously rotating motor drive of the scanning valve was found to be inappropriate. This drive not only changed the signal characteristic when connecting and disconnecting the input ports to the scanning valve transducer but also may not allow sufficient sampling time for the spectrum analyzer to achieve good averaging accuracies. A stepping motor drive would be more suitable for this purpose. This would be very useful in case of a pressure perturbation having time dependent amplitudes (as encountered in this study) which would require longer sampling times.

b. It is extremely essential to be aware of the presence of spatial variations in the pressure perturbations. It was observed that even for small differences in the physical location of the measurement points, different amplitude signals were present. These, if measured and compared by the implanted and scanning valve transducers, could lead to erroneous conclusions about the measurement accuracies of the tube-scanning valve system.

c. At high wind tunnel speeds, large pressure perturbations can be achieved for relatively small physical oscillations of the perturbation introducing mechanism (Ref 9). This would reduce structural vibrations considerably, and the measurements made by the implanted transducer could be used for comparison studies.

d. The flap-airfoil gap was found to be affecting the sinusoidal characteristics of the pressure perturbations.

e. Stronger excitation sources for the pressure perturbation introducing mechanism are needed for this wind tunnel. These excitors would be able to introduce higher frequency pressure perturbations, broadening the verified frequency band in which the tube-scanning valve system can be used with confidence.

VI. Recommendations

In light of the conclusions made from this study, the tube-scanning valve measurement system can be used more effectively by incorporating the following improvements.

a. Theoretical and experimental investigations should be carried out to establish accuracy of the system for a nonsinusoidal pressure signal. This would allow the system to be used in a more practical environment.

b. To study the effects of sinusoidal pressure perturbation over a flap-airfoil model, it should be ensured that there is no air leakage from the flap-airfoil gap. An internal flexible fabric seal can be used for this purpose.

c. The pressure perturbation introducing mechanism should be designed such that the perturbation amplitudes are not time dependent. This would reduce the sampling time considerably without sacrificing averaging accuracy.

d. The instrumentation should be improved. The use of a spectrum analyzer with tape recording capability would reduce the wind tunnel usage time by allowing data reduction at a later time.

e. A scanning valve with a stepping motor/solenoid drive with controllable stepping speeds should be utilized. An identification of the port being recorded by the spectrum analyzer would be highly desirable, if the measurements are large in number. The signal from a shaft position encoder-decoder fed appropriately to the tape recording device can be used for this purpose.

f. Stronger excitation sources should be used for the pressure perturbation introducing mechanism.

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The application of pneumatic tranmission lines theory to a tube-scanning valve system for unsteady pressure measurements in the AFIT 5-foot wind tunnel is investigated. Transfer gains of various tube-scanning valve configurations were experimentally measured and the validity of a theoretical model verified for a frequency range of 20 Hz to 140 Hz.

The selected system having a 0.0625-in. ID flexible tube of 84 in. length connected to a scanning valve was installed in the wind tunnel. Unsteady pressures introduced over an 18 percent airfoil at zero angle of attack (cont)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) were measured with this system. Data were collected for 0, 40, 60, 80, 100, and 150 mph for a frequency range of 30 Hz to 55 Hz. Comparison of theoretical and experimental results for one data point revealed the dependence of the verification of the system measurement accuracy on the wind tunnel speeds and flow perturbation characteristics. Theoretical predictions were verified for 30, 35, and 40 Hz only.